INDOOR COMFORT EVALUATION OF A SUSTAINABLE WOODEN HOUSE WITH A NOVEL VAPOR-OPEN ENVELOPE SYSTEM IN SUBTROPICAL CLIMATE

Y. Goto[1]; Y. Ostermeyer[1]; H. Wallbaum,[1]

1: Chalmers University of Technology, Sven Hultins gata 8, SE-41296 Gothenburg, Sweden

ABSTRACT

Concerning the resource depletion and global warming, the realization of sustainable constructions is crucial because the building industry has a big impact on the greenhouse gas emission. Recently the interest in the buildings in subtropical regions has been growing due to the high growth rate of their urbanized areas. From the view point of building physics, those regions are very challenging because they have both heating and cooling demand. Also the prediction of indoor air humidity is acquiring a greater interest concerning the envelope durability, the comfort and the energy consumption, which is very relevant to such regions. Meanwhile, there is a need of developing a new construction system and its design method for subtropical regions since it is inappropriate to simply use the established construction systems for cold regions which have only heating demand.

Based on the transient hydrothermal model of the envelope and the whole building heat and moisture balance model taking into account the moisture buffering by hygroscopic interior materials, the authors have developed an envelope system and its insulation optimization scheme which considers lifetime environmental impact, lifetime cost, durability, users' behaviour and local climate. The envelope consists of natural materials such as wood and clay and thus allows the moderate transfer of the water vapour in both directions i.e. from exterior to interior and from interior to exterior. A detached house with this system was realized in Ohmihachiman (central Japan) in June 2013 and the indoor temperature and humidity have been monitored at several points.

The measured indoor climate was analysed and it was revealed that 1. the indoor climate in summer has a certain improvement potential and 2. the indoor climate in winter is satisfying. As the monitoring of electricity generation by the photovoltaic panels and the electricity consumption of the whole house has showed a positive balance (more generation than consumption), it is suggested to either use the cooling radiator more actively or install an active dehumidifier into the mechanical ventilation system to provide a more agreeable indoor cli-mate in the summer. The former recommendation will be implemented in summer 2015 and its impact on the comfort and energy consumption will be further analysed.

Keywords: vapour-open envelope, subtropical climate, indoor comfort, wooden building

INTRODUCTION

Concerning the resource depletion and global warming, the realization of sustainable constructions is crucial because the building industry has a big impact on the greenhouse gas (GHG) emission. The rapid economic development and urbanization in subtropical regions is a major issue with regard to the reduction of GHG emission and the mitigation to global warming. As the construction industry plays a significant role, there is a need for innovations on building technologies in those regions [1]. From the view point of building physics, those regions are very challenging because they have both heating and cooling demand. Also the prediction of indoor air humidity is acquiring a greater interest concerning the envelope durability, the comfort and the energy consumption, which is very relevant to such regions. Meanwhile it is crucial to take into account that there is an enormous socio-cultural diversity and different economic situations among the regions, which needs to be thoroughly taken into account when applying and developing new technologies to and for these regions.

The authors have developed a vapour-open wooden building envelope system and the optimization method of its insulation layer for central Japan, which has typical subtropical climate conditions, and evaluated its sustainability aspect from environmental, economic and building physics perspective with a sound consideration of the local socio-cultural context [2, 3, 4]. This study presents the evaluation of indoor comfort of a test house which was realized using this envelope system in Ohmihachiman (central Japan) in June 2013.

METHOD

Vapour-open wooden building envelope for subtropical regions

A new building envelope system was developed within the research team led by the authors. This envelope system mainly consists of major layers with natural materials, namely the external insulation layer with wood fiber board, the structural layer with cross laminated wooden panel and the interior finishing layer with the composite of wood and clay. The illustration of the envelope system and the materials for each layer is shown in Figure 1. The basic design philosophy of this system is that the envelope consists of hygroscopic materials with moderate vapor permeability. This system allows the moisture flux to move through the wall in both directions. By defining the appropriate thickness to each layer, it is possible to avoid moisture related problems inside the wall by humidity buffering.

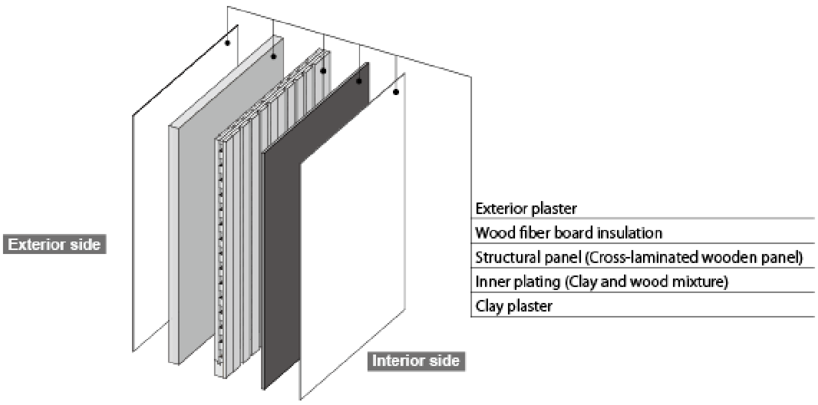
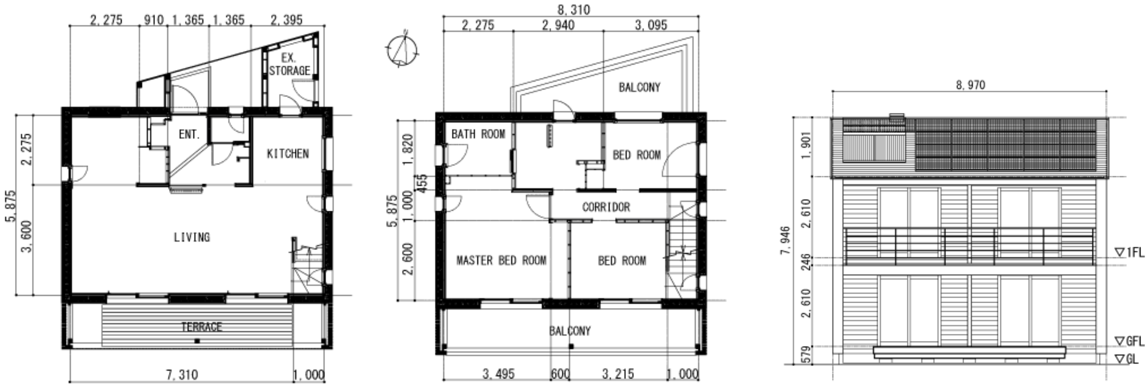


Figure 1: Layered structure of the vapour-open envelope for subtropical regions.

The test house and the measurement setup

In June 2013, a residential building with the envelope system was realized in Ohmihachiman (central Japan) which has a typical subtropical climate with hot-humid summer and cold-dry winter. The general design of the building was done by local architects and the technical supervision was done by the research team. The building is a detached residential building where two to four persons (two adults and up to two children) are supposed to reside. Apart from the basic layered design presented in Figure 1, the surface of the insulation was covered with vapour-open water-tight membrane. Air-tight membrane was applied between the insulation and the structural panel. The concrete foundation was designed to have a flat surface and to be covered with asphalt sheet so that the control of heat and moisture transfer through it becomes the least intricate. The roof was based on the conventional design with air venting layer. Figure 2 shows the plan and elevation of the test house.



(a) *(b)* *(c)*

Figure 2: Plan and elevation of the test house. (a: the floor plan of the ground floor, b: the floor plan of 1st floor, c: the elevation of south façade)

Based on LCA, LCCA and hygrothermal analysis considering the specific design conditions [2, 3, 4], the insulation (thermal conductivity lamda: 0.038 W/mK) thickness was decided to be 18 cm. The other solid components of the envelope were 90 mm thick cross laminated timber panel with air gaps (lamda: 0.110 W/mK considering the effect of the air gap), For the openings air-tight and triple grazing windows (0.7 W/m^{2}K), 14 mm thick clay board (lamda 0.299 W/mK) and 4mm thick clay plaster (lamda: 0.590 W/mK). The U-value of the wall was thus 0.158 W/m^{2}K. Photovoltaic (PV) panels cover the south roof (4.18 kWp) combined with solar water heater panels for domestic hot water supply. The building orientation and the shading of the openings were carefully decided considering the balance of solar gain in summer and winter. As for HVAC system, radiators for heating and cooling-dehumidification and mechanical ventilation with heat exchanger were employed. The façade consists of cladding with ventilation gap.

Figure 3 shows the finished house. In order to measure the indoor climate and the conditions inside the external walls, 21 temperature and humidity sensors were installed. Figure 4 shows the sensor and sensor node. The measuring points are; northern side wall on the ground floor (5 points across the wall from the living room to the exterior), living room, kitchen, northern side wall on the 1st floor (5 points from the bathroom to the exterior), west side wall on the 1st floor (5 points from the master bedroom to the exterior), northern side roof (4 points from the attic to the exterior). The measurement started in September 2013. The data logging interval is set at 10 minutes. The preliminary validation investigation on the heat and moisture transfer across the envelope was reported in [5].

Figure 3: The completed house. (left: east side façade, right: living room on the ground floor)

Figure 4: The installation of sensors. (left: an sensor inserted between air-tight membrane and insulation, right: a sensor node box)

RESULTS

Figure 5 shows the exterior condition (temperature and humidity in the ventilation gap under the façade cladding) on the north side in the first floor of the building. The measurement was interrupted in February due to a technical reason (a battery problem). Figure 6 shows the measured temperature and relative humidity of the living room on the ground floor and that of the master bedroom on the first floor in 2014.

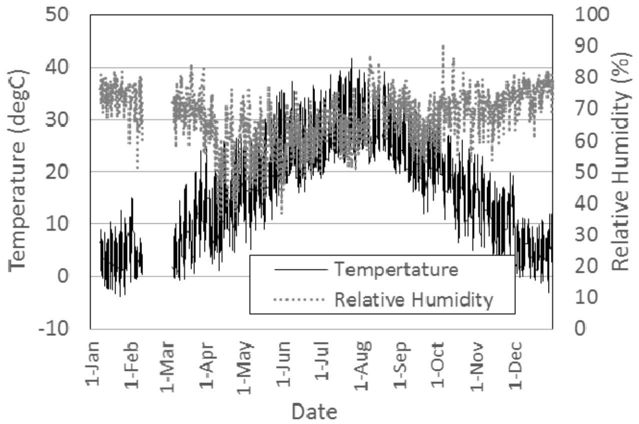


Figure 5: Temperature and relative humidity in the ventilation gap in the north wall

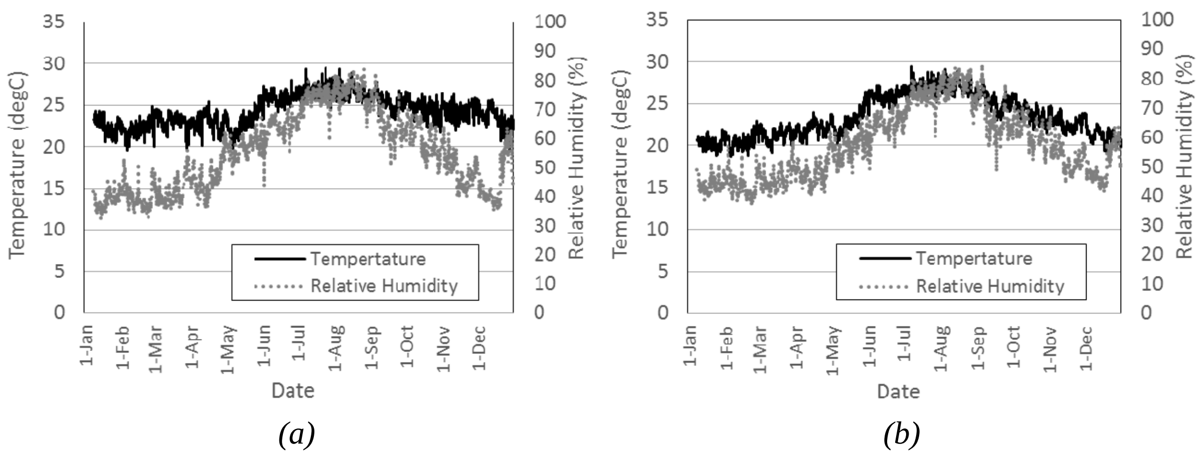


Figure 6: Measured indoor temperature and relative humidity. (a: living room on the ground floor, b: master bedroom on the first floor)

As these two different rooms in different locations in the building showed a similar condition, the following discussion focuses only on the condition of the living room.

In order to evaluate the indoor comfort, the acceptability-index (Acc.) proposed by Fang et al. was applied [6]. By this method, the indoor air quality can be defined based on the air temperature, humidity and the pollution level. Acc. Is given between 1.0 and –1.0. The higher the value, the more comfortable is the air. Figure 7 shows the acceptability-index in the living room throughout 2014 disregarding the effect of neither CO_2 concentration nor contamination by hazardous gasses.

Table 1 lists the measured electricity supply by the PV panel and electricity grid and its consumption by the cooling unit and the entire household (the whole electricity demand including the consumption by the cooling unit).

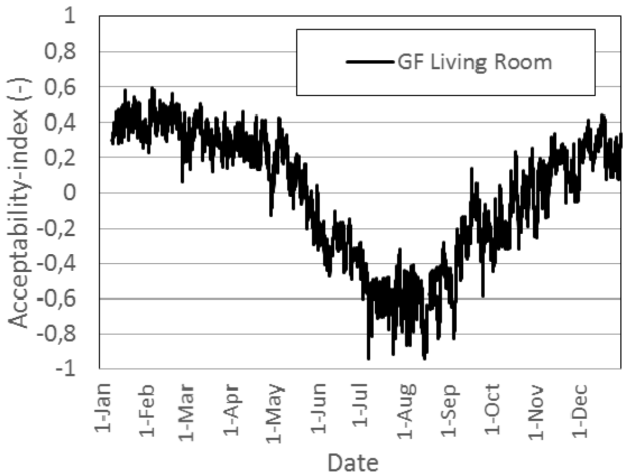


Figure 7: Acceptability-index of the living room based on the measured values.

	Energy (kWh)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Consumption by heating/cooling unit	246.6	182.3	163.7	84.4	98	0	61.8	78.3	0	28.2	55.8	204.4
Production by PV panel	371.3	360.9	453.3	555.7	576.7	506.3	536.5	417.2	501.2	430.2	211.7	315.9
Electricity sold	209.8	207.8	298.4	420.0	421.1	421.1	371.4	266.0	413.4	338.7	148.2	190.4
Electricity bought	417.9	309.7	269.7	149.4	75.2	70.9	137.8	167.0	85.1	124.7	112.7	344.0
Electricity demand	579.4	462.8	424.7	285.1	162.3	156.2	302.9	318.1	172.9	216.1	176.2	469.5

Table 1: Electricity supply and consumption in summer 2014

DISCUSSION

Figure 7 shows that the indoor climate in the winter was satisfying while the energy (electricity) consumption for heating was low (11.0 kWh/m^{2}a in which the electricity was partly supplied by the PV panel). Regarding the summer, it reached uncomfortable level (lower than Acc. value of -0.4) for about three months (June-August). The reason for this was obviously high level of both temperature and relative humidity. This implies that the cooling radiator which works by electricity and as dehumidifier as well did not contribute to create a comfortable indoor environment. The reason is either reduced use of the cooling unit or its insufficient capacity. It shows a positive balance (more production than consumption), which means that the electricity production by the PV panel was large enough to allow more cooling throughout the summer period. In fact, as the first year experience, the inhabitants tried to live in the house with the least energy consumption with a certain sacrifice on the comfort. Therefore it is recommended to use the cooling unit more actively in order to reach better comfort level in the summer.

CONCLUSION

In this study, the indoor comfort of a residential building in Japan with a vapour-open wooden building envelope system for subtropical climate is analysed. The indoor climate measurements showed that the comfort level in the summer has the potential to be improved while the winter condition was satisfying with low energy consumption. The energy consumption for cooling and dehumidification showed that it had significant surplus of energy by the PV panel throughout the cooling season. Therefore it is recommended to use the cooling system more actively in order to acquire better comfort. This will be implemented in summer 2015 and its impact on the comfort and energy consumption will be further analysed.

ACKOWLEDGEMENT

The authors would like to express the gratitude to EIT Climate-KIC flagship program Building Technology Accelerator for the grant, Dr. Karim Ghazi Wakili and Roger Vonbank of Empa for the support of the measurement and Mr. and Mrs. Iida for providing the possibility to carry out the project and measurements in the house in Ohmihachiman.

REFERENCES

1. CIB & UNEP-IETC: Agenda 21 for Sustainable Construction in Developing Countries, 2002.
2. Goto, Y., Ghazi Wakili, K., Ostermeyer, Y., Frank, T., Ando, N., Wallbaum, H.: Preliminary investigation of a vapor-open envelope tailored for subtropical climate. Building and Environment, Vol 46, pp 719–728, 2011.
3. Goto, Y., Ghazi Wakili, K., Frank, T., Stahl, T., Ostermeyer, Y., Ando, N., Wallbaum, H.: Heat and moisture balance simulation of a building with vapor-open envelope system for subtropical regions. Building Simulation, Vol 5, pp 301–314, 2012.
4. Goto, Y., Ostermeyer, Y., Ghazi Wakili, K., Wallbaum, H.: Economic, ecological and thermo-hygric optimization of a vapor-open envelope for subtropical climate. Energy and Buildings, Vol 46, pp 719-728, 2012.
5. Goto, Y., Ostermeyer, Y., Ghazi Wakili, K., Frangi, A., Ando, N., Wallbaum, H.: Sustainable wooden envelope for subtropical regions - The realization and validation in Japan. WCTE 2014, Quebec City, Canada, 2014.
6. Fang, L., Clausen, G., Fanger, P.O.: Impact of temperature and Humidity on the Perception of Indoor Air Quality. Indoor Air, Vol 8, pp 80-90, 1998.